FREQUENCY AND PERSISTENCE OF LOW-WIND-POWER EVENTS IN GERMANY

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Overview

The Paris Agreement calls for an extensive decarbonisation of the global economy. In this context, the expansion of variable renewable energy sources, in particular solar photovoltaics (PV) and wind power, will play a major role. While power generation from solar PV largely follows diurnal and seasonal cycles, wind power is subject to more irregular inter-annual as well as intra-annual fluctuations which give rise to security of supply concerns. In countries with growing shares of wind power, the occurrence of low-wind-power (LWP) events thus receives increasing attention. This is particularly true in Germany. Given the government's targets to expand the share of renewables in electricity consumption to at least 80% by 2050, the dependence of the German energy system on wind power is set to increase strongly in the future.

Yet dedicated research on LWP events is sparse so far. We aim to fill this gap, focusing on onshore wind power. We examine the frequency, persistence, and magnitude of German LWP events, making use of reanalysis data for 36 full years (1981 to 2016) and state-of-the-art power curves. In doing so, we look at different thresholds of capacity factors (2%, 5% and 10%) and two definitions of LWP events. We also compare the spatial distributions of LWP events and mean wind power generation. Parts of our analysis focus on winter months. These appear to be particularly relevant, as power generation from solar PV is also relatively low in winter. In order to allow for the highest degree of transparency and reproducibility, we provide the source code and all input data of our analysis under dedicated open-source licences.

Methods

Based on wind speeds and power curves, we derive an hourly aggregated time series of capacity factors for wind power in Germany. First, we take wind speeds on 50 meters above surface from the MERRA-2 reanalysis dataset, which covers 36 years from 1981 to 2016, and extrapolate to hub heights. Second, capacity factors of each MERRA-2 polygon are calculated based on power curves of current wind turbines. Finally, these capacity factors are spatially aggregated using a weighting scheme considering the current spatial distribution of onshore wind power capacity in Germany (Fig. 1). We subsequently analyse the time series of hourly aggregated capacity factors by applying a narrower and a wider definition of LWP events: we either consider LWP events as consecutive hours which are constantly below a given capacity factor threshold (CBT), or we consider LWP events to consist of hours in which the mean (i.e. moving average) capacity factors is below the same threshold (MBT, Fig. 2). We then analyse the seasonal distribution of LWP events in Germany, followed by an examination of the duration and spatial distribution of the most extreme events.

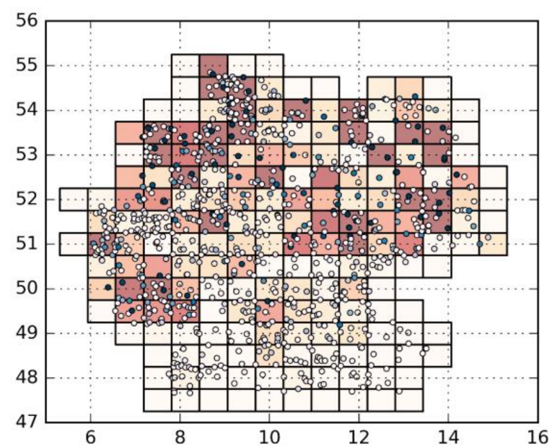

Figure 1: Installed wind power capacity and weighting

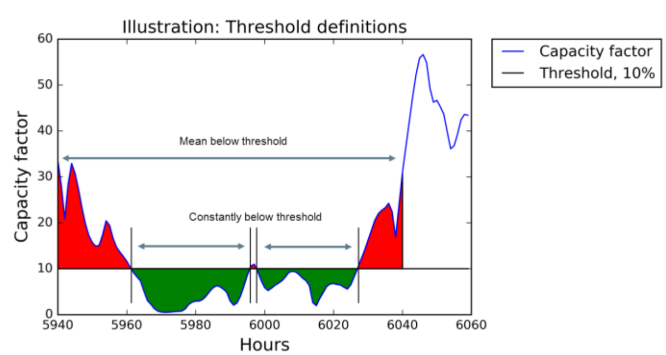

Figure 2: Low-wind-power event definitions

Results

For both LWP definitions, events are generally most frequent in summer (June-August) and least frequent in winter (December-February), independent of the duration. The results for spring (March-May) and autumn (September- November) are mostly close the annual average. The frequency of events for a given persistence is about 1.5-3 times higher for the MBT definition compared to CBT. For both definitions, the chosen threshold value has a strong effect. For example, a 10-hour event below a capacity factor of 2% (MBT) occurs on average once per winter. For a 10% threshold, there are 15 such events on average (Fig. 3).

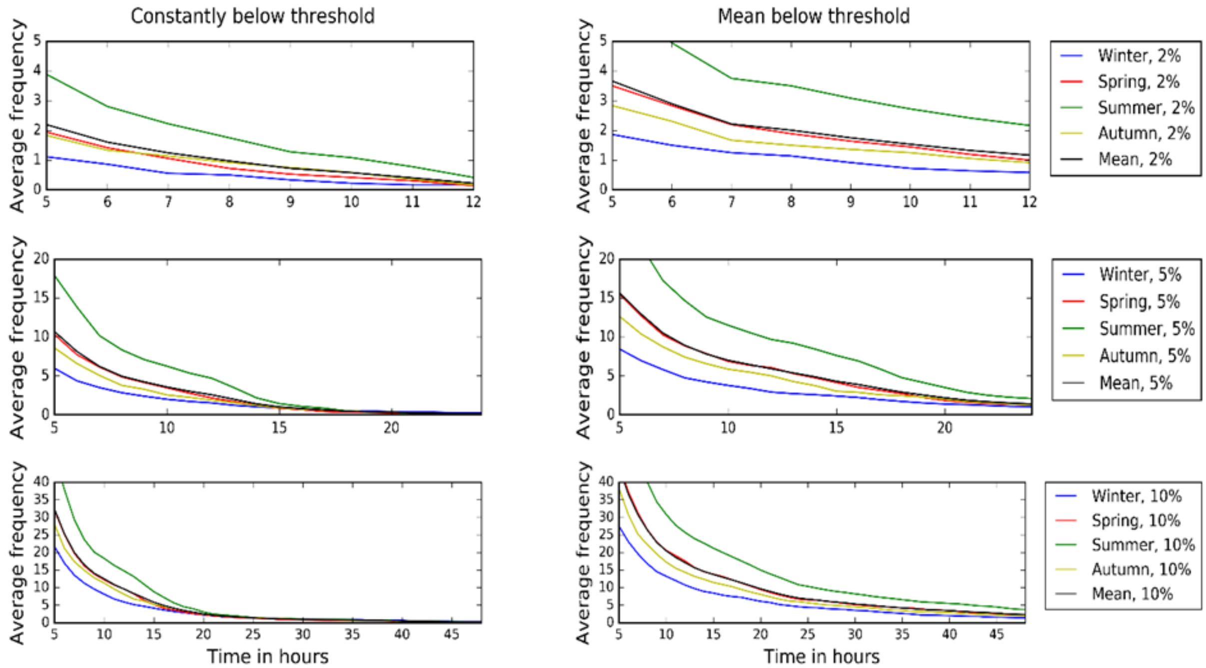

Figure 3: Average seasonal frequency and persistence of LWP events in Germany

For a return time of ten years, we find a persistence of 14 (2% capacity factor), 33 (5%) and 64 hours (10%) in winter months under the CBT definition, and 28 (2%), 69 (5%) and 117 hours (10%) under MBT. In other words, every 10 years the German energy system has to deal with an 33(69)-hour event of average wind power generation below 5% of the installed capacity under the CBT (MBT) definition.

We further investigate the most extreme LPW events in the 36 years analysed, as these may be considered as a kind of benchmark of required backup or alternative production capacities for energy system planners. The most extreme events for both definitions and over all threshold occurred in 1985, and there are extremely large inter-annual variations. Considering the 10% threshold, the longest event for the MBT definition lasted for almost 10 days in 1985. On the contrary, in 2005 there were only three days for the same threshold. As for single months, we find that the most extreme events for the 10% threshold occurred in March (1985) for both definitions. For the other thresholds, the most extreme events are found in again March and additionally in February.

As regards the geographic distribution of low-wind events, we find that the pattern of the spatially disaggregated mean capacity factors for the lowest MBT period substantially deviates from the geographic pattern of the annual mean wind power generation. Especially the north-eastern German region has relatively low mean capacity factors. Yet there is no consistent geographical pattern for the three thresholds and two LWP definitions used in this analysis.

Conclusions

Coping with low-wind-power events becomes increasingly important in power systems with growing shares of variable renewables, and LWP events in winter months appear to be most challenging. Our analysis for Germany shows that the likelihood for extreme LWP is generally smaller in winter than in summer, but power system planners should be prepared for extreme events also to occur in winter months. Further, the magnitude of low-wind power events differs strongly between the years. Studies only considering one year or a small sample of years are likely to underestimate the possibilities of low-wind power events and should thus not be used to inform policy makers with respect to power system planning. Further, our finding that the geographical distribution of LWP events does not necessarily correspond to annual mean wind power generation patterns implies substantial challenges for decentralised electricity supply concepts. As the future German power system will neither be isolated, nor based on onshore wind power alone, future research should include PV and offshore wind while expanding the geographic focus beyond Germany in order to raise further insights.